CONFLICT RESOLUTION IN MULTI - AGENT SYSTEMS

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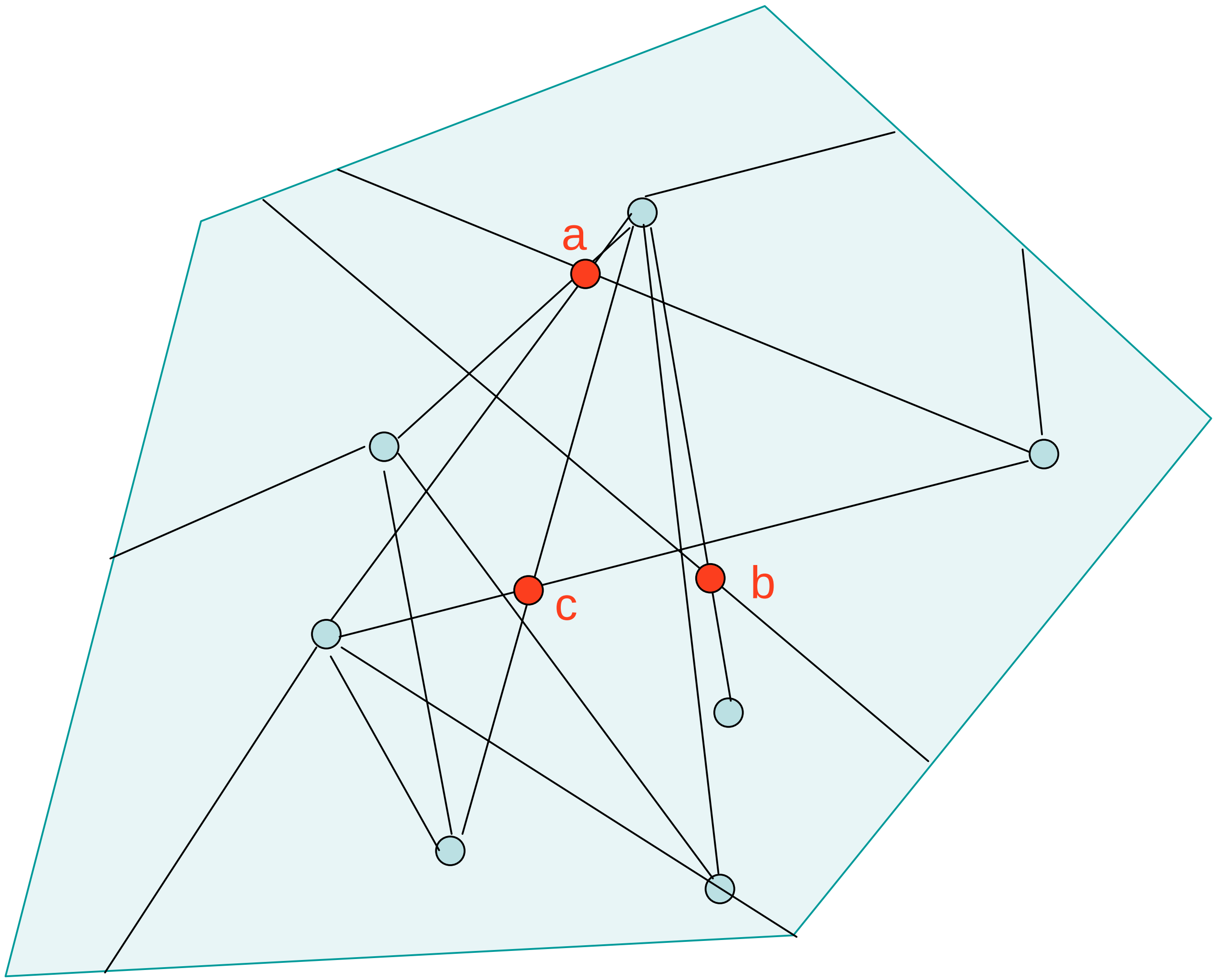
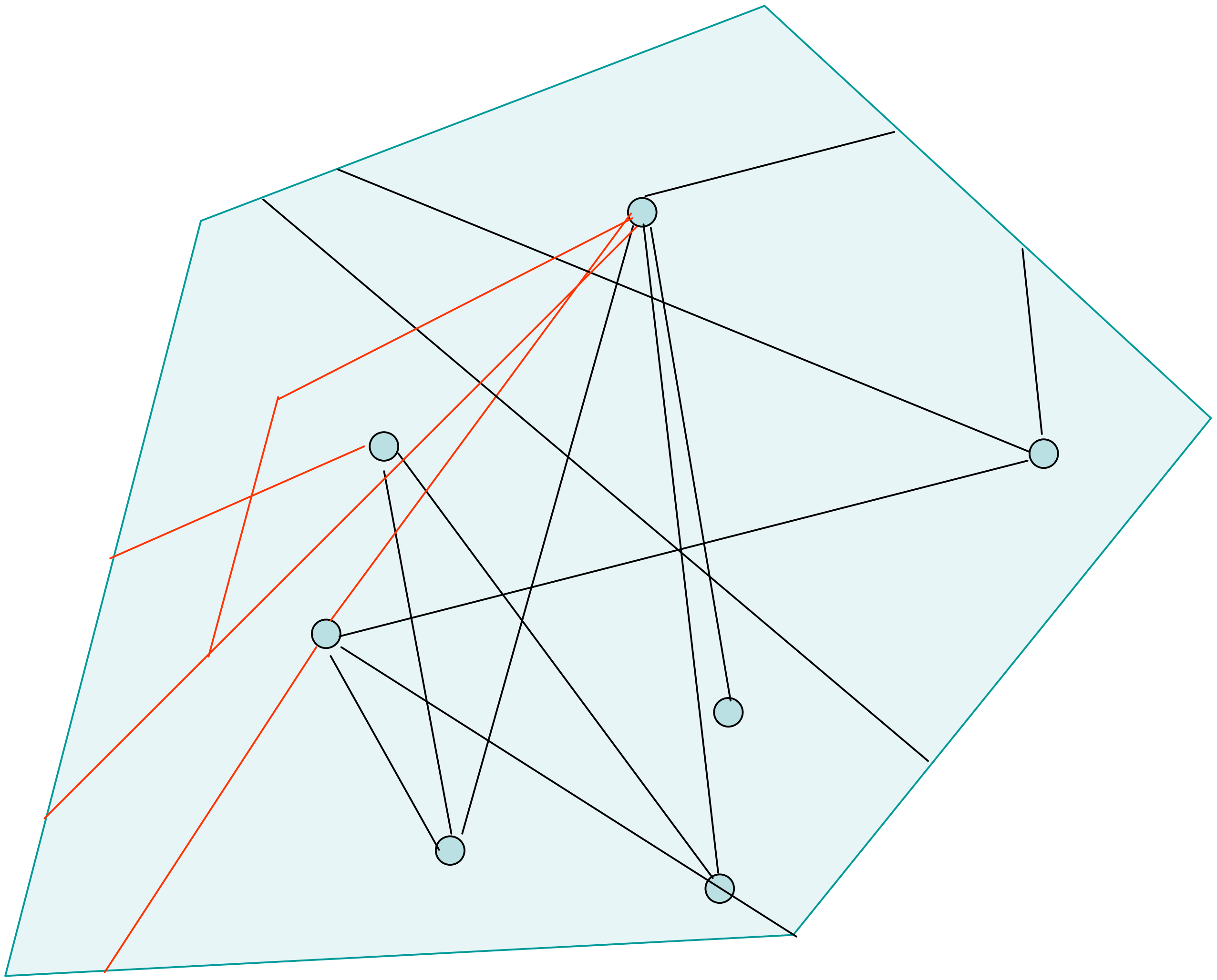
Outline

1. Motivation
2. Objective
3. Formalism
4. Algorithm
5. Example
6. Generalization
7. Future directions
8. Summary

Airspace fragment



Bundle of trajectories



Problem

- structure: R4, trajectories, protective zone, tubes
- conflict: intersection of tubes – subset of R4
- alternatives: a bundle of trajectories per flight (agent)
- safety: no common events (resources)
- efficiency: fair distribution of resources
- computational complexity: MILP – exponential (5000 ag)

Develop methodology for pre-selection of trajectories

1. SAFE
2. FAIR
3. TRACTABLE

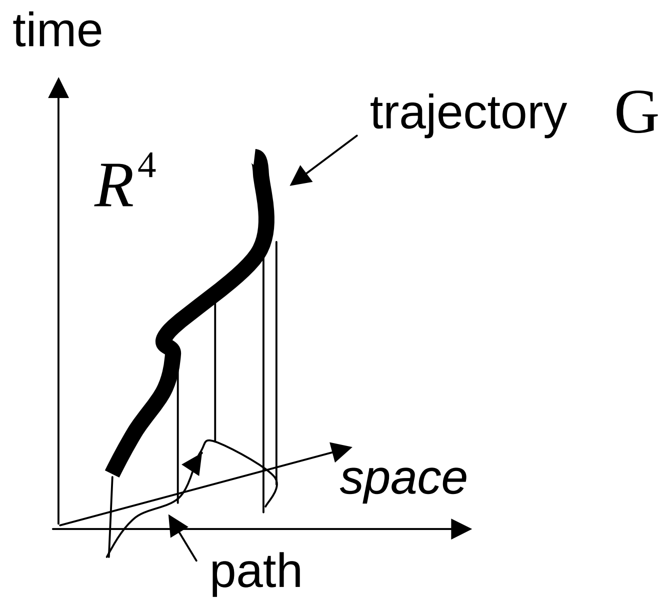
Approach

- discrete alternatives (bundles)
- map all trajectories in R4 into a network
- include only conflicted resources e_k
- map trajectory into sequence

$$\Gamma = \{(t, r(t)), t \in T\} \Rightarrow \Gamma^{*} = e_1 e_2 e_3 \ldots e_n$$

- oriented string: temporal consistency
- introduce prioritization of resources
- define a global rule of behavior
- construct resolution algorithm

Resources

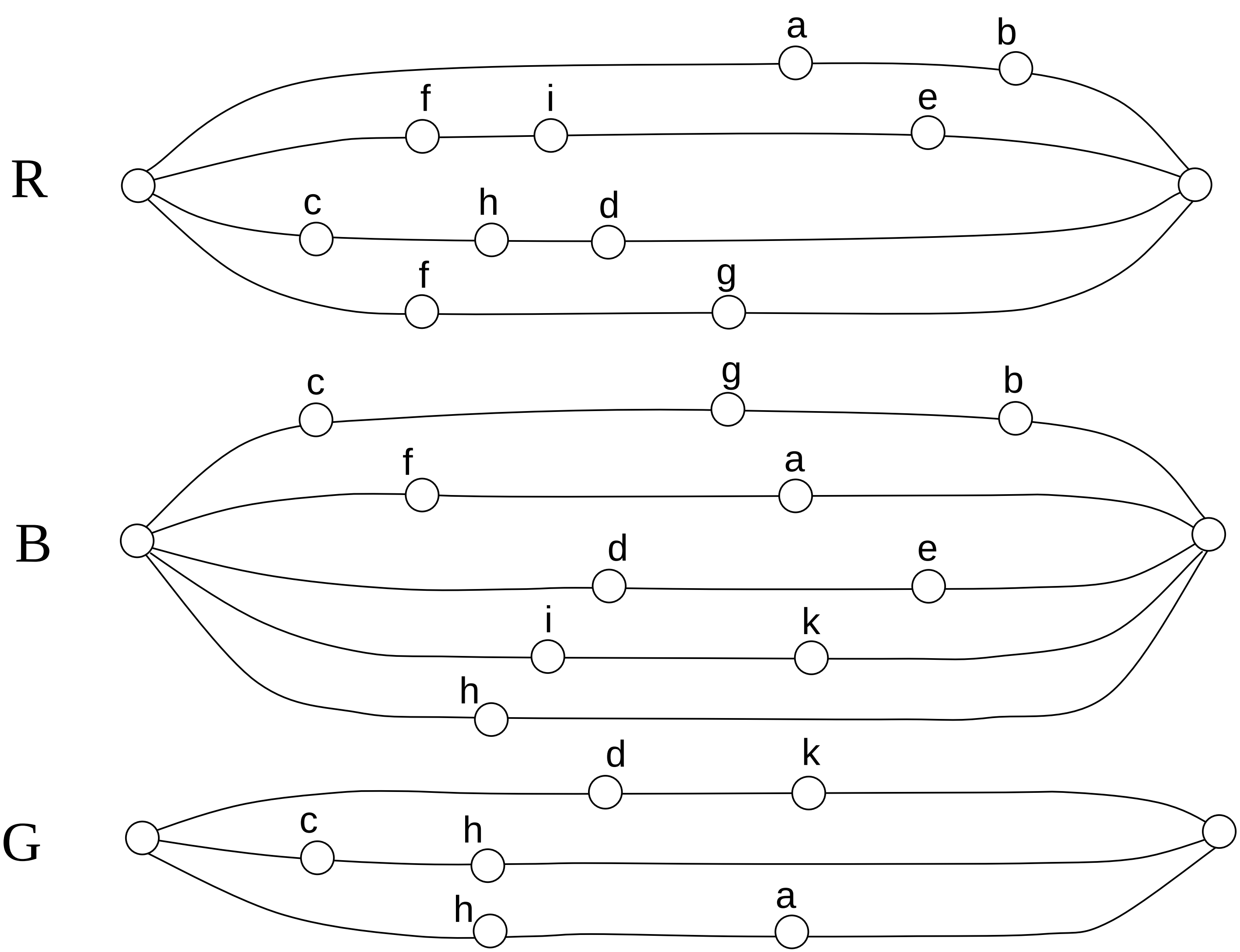


4-D trajectory $\Gamma = \{(t, r(t)), t \in T\}$

3-D path $\rho = \{r(t), t \in T\}$

conflicting resource: intersection of tubes $\varepsilon = \delta t \times \delta r$

Bundles of trajectories

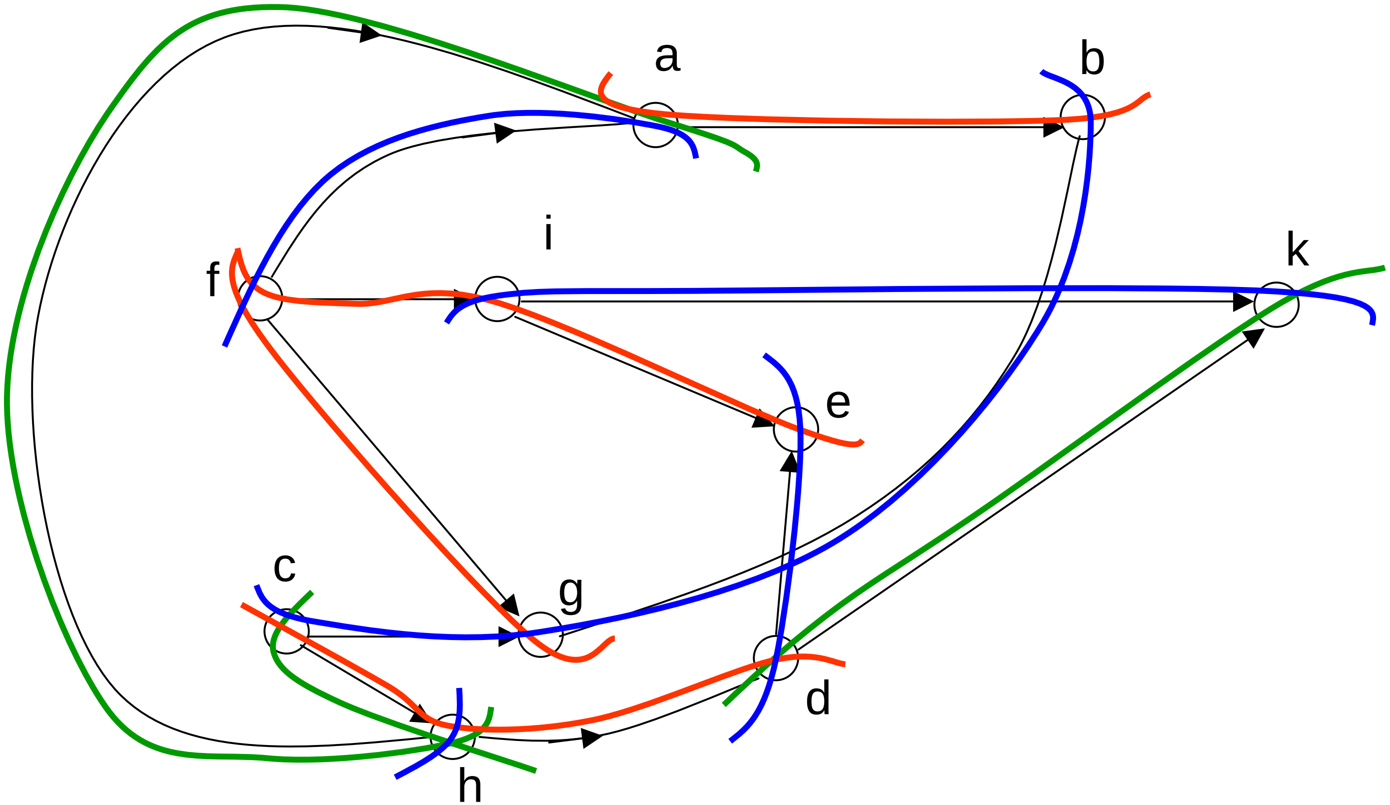


Trajectories on directed graph of conflicts

R={ab,fie,chd,fg}

B={cgb,fa,de,ik,h}

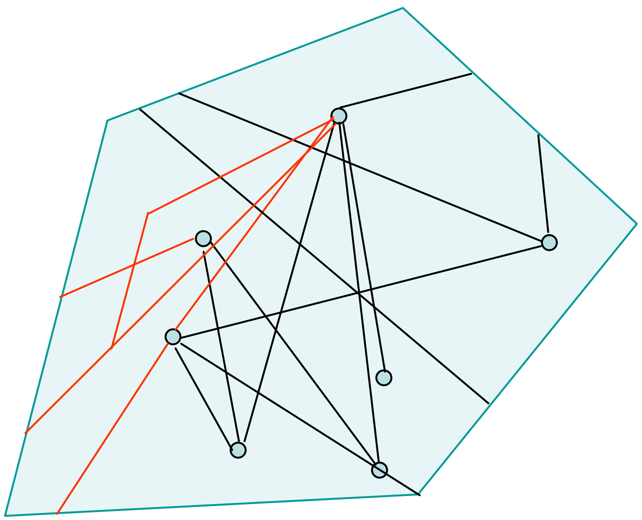
G={dk,ch,ha}



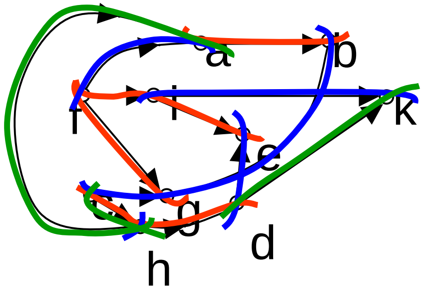
Conflict table

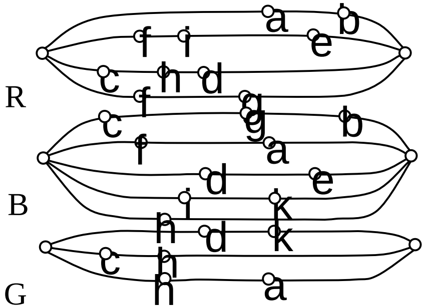
a	{R,G,B}
b	{R,B}
c	{R,G,B}
d	{R,G,B}
e	{R,B}
f	{R,B}
g	{R,B}
h	{R,G}
i	{R,B}
k	{G,B}

Discretization



polynomial





a	{R,G,B}
b	{R,B}
c	{R,G,B}
d	{R,G,B}
e	{R,B}
f	{R,B}
g	{R,B}
h	{R,G}
i	{R,B}
k	{G,B}

Objectives

- methodology for pre-selection of safe trajectories
- distributed
- no cooperation
- no communication
- greedy agents

Priority function

conflict table

a	{R,G,B}
b	{R,B}
c	{R,G,B}
d	{R,G,B}
e	{R,B}
f	{R,B}
g	{R,B}
h	{R,G}
i	{R,B}
k	{G,B}

$\xrightarrow{p}$

priority table

a	(RGB)
b	(B,R)
c	(R,B,G)
d	(G,B,R)
e	(R,B)
f	(B,R)
g	(R,B)
h	(G,R,B)
i	(R,B)
k	(B,G)

Global rules of behavior

1. An agent claims a contested resource *e* on a trajectory if and only if

    a. it has claimed prefix of *e*
    b. it has highest priority for *e* among all agents that have claimed own prefix of *e*.

2. A trajectory is designated to an agent if it can claim all the resources on the trajectory

3. Agents are greedy

Formal model

1. oriented resource graph: nodes = disputed resources
2. trajectory: sequence $\mathrm{G}^* = eabcde$, order, prefix, suffix
3. agent: $P = \{\mathrm{G}_1^*, \mathrm{G}_2^*, \ldots, \mathrm{G}_n^*\}$
4. conflict: common occupancy
5. prioritization p
6. global rule of behavior

Conflict Resolution

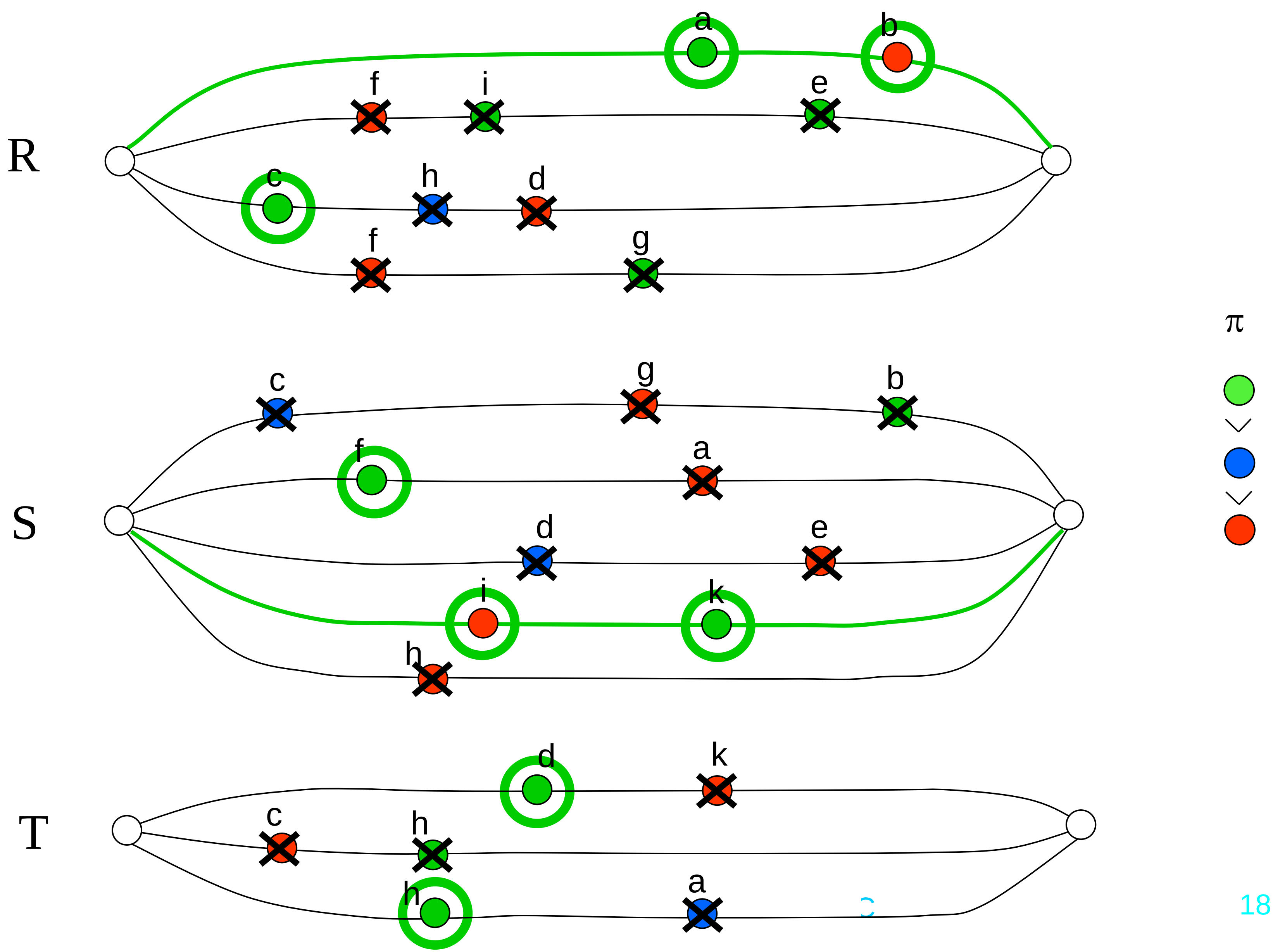
- Given a multi-agent system $\{\mathcal{P}_1, \mathcal{P}_2, \ldots, \mathcal{P}_n\}$
- And a prioritization of agents over contested resources
- Find for each agent a legal plan $Lp_i \subseteq \mathcal{P}_i$, such that
- $(Lp_1, Lp_2, \ldots, Lp_n)$ satisfies the above global behavior rule.

Iteration

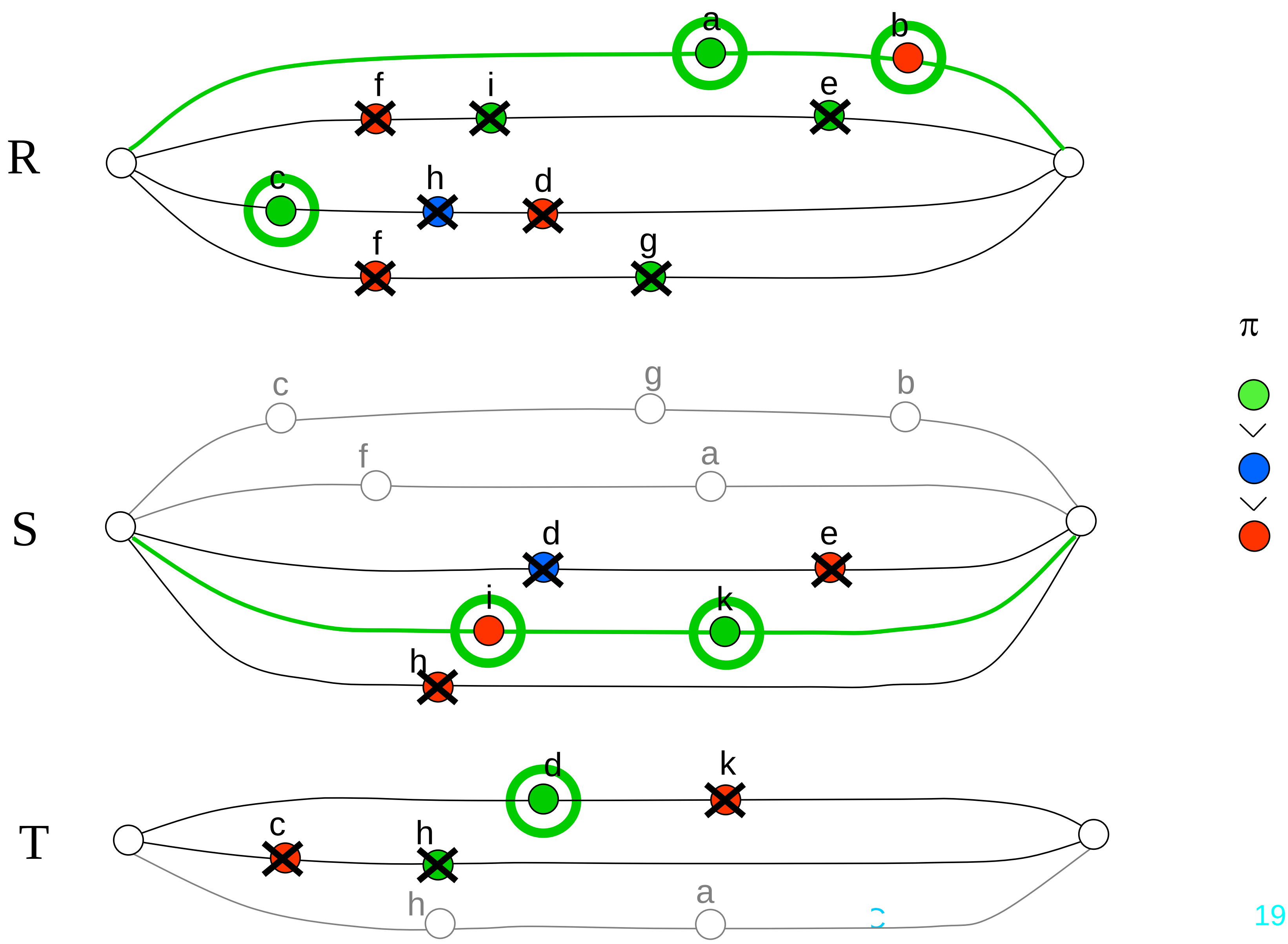
- Claim by prioritized access:
- The initial resource is claimed
- Prioritized access: claim all preceding resources on a path
- Claim: highest priority among all agents having prioritized access.

- Path designation: all resources claimed

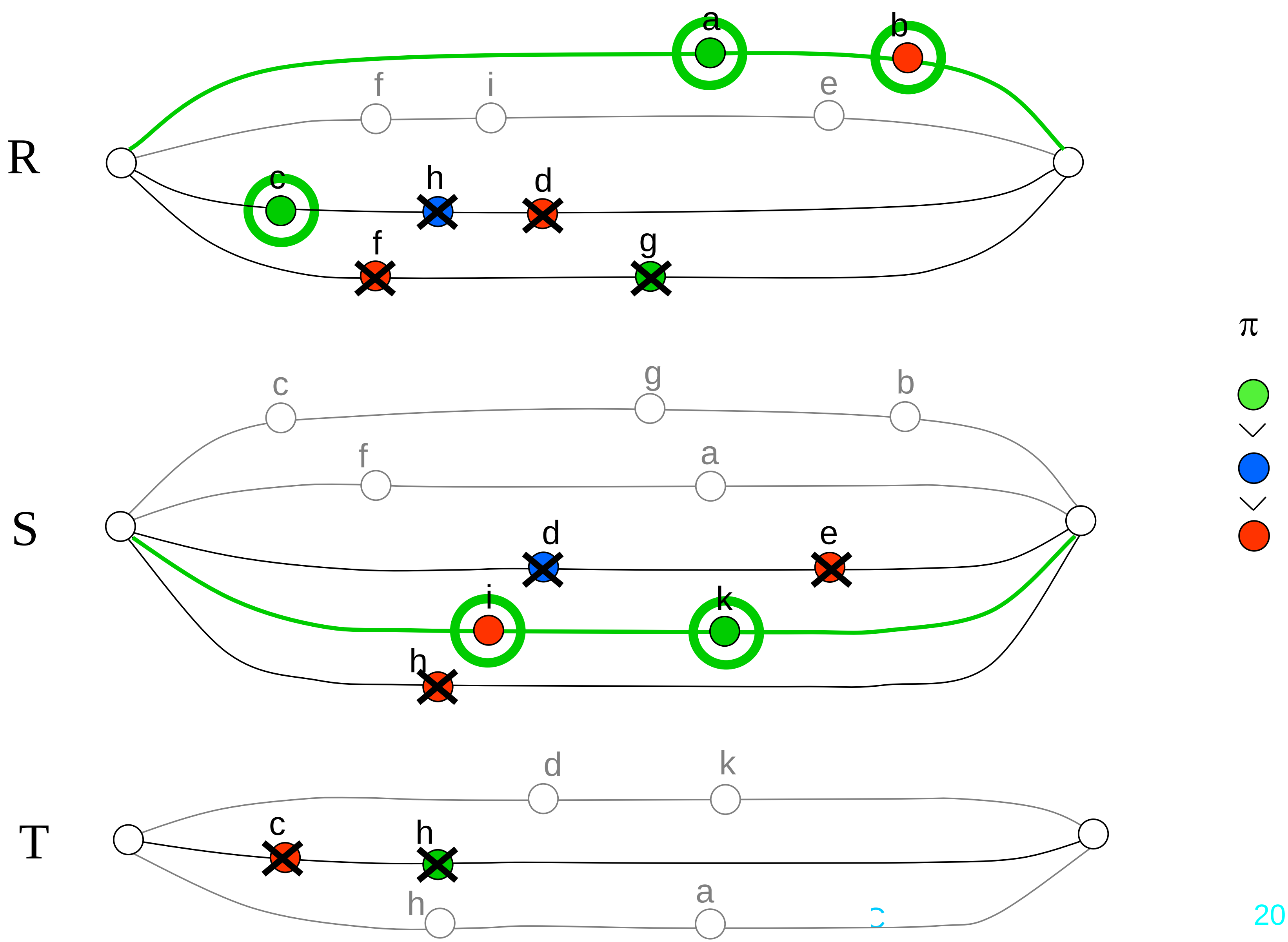
The algorithm



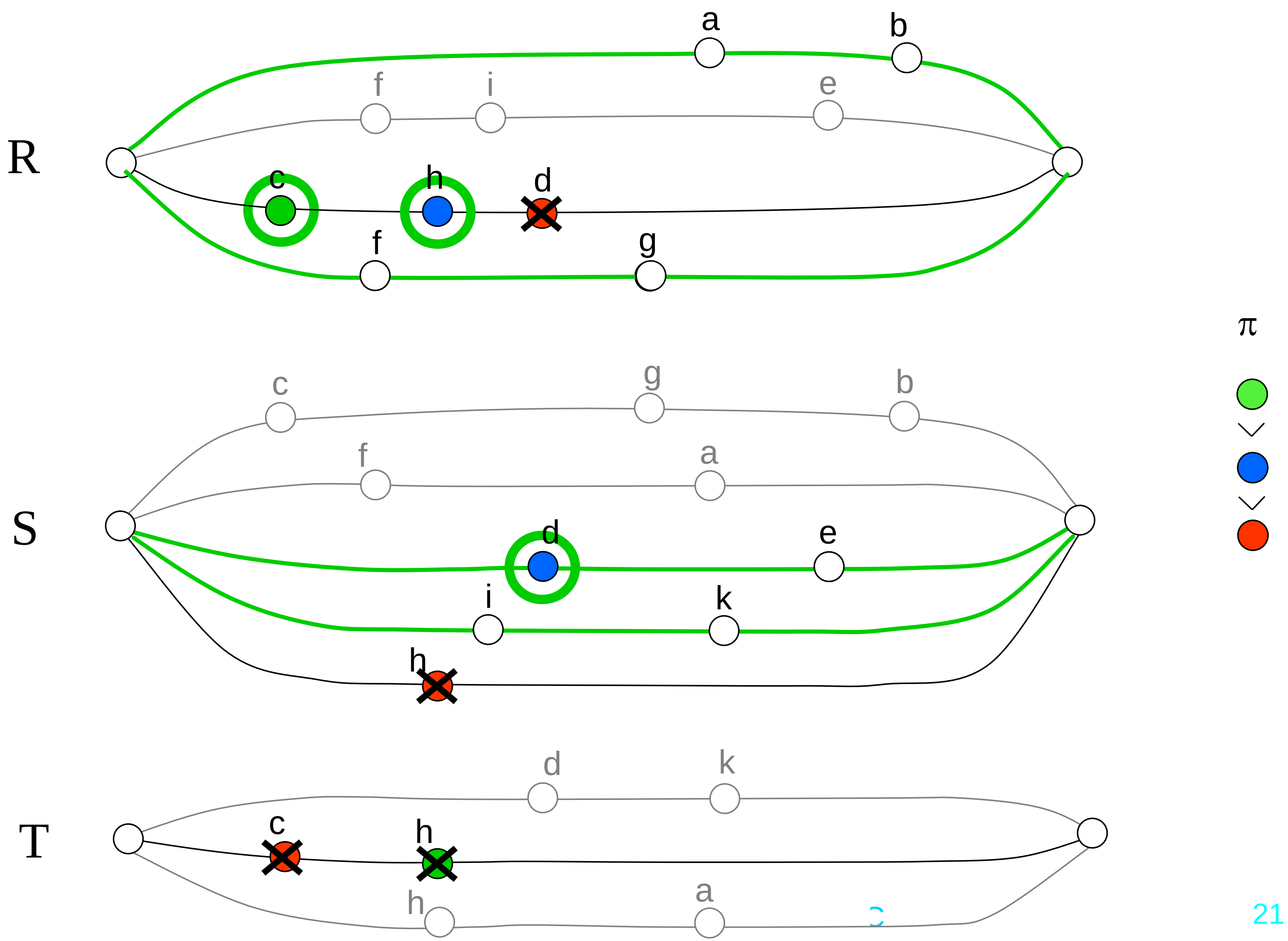
The algorithm



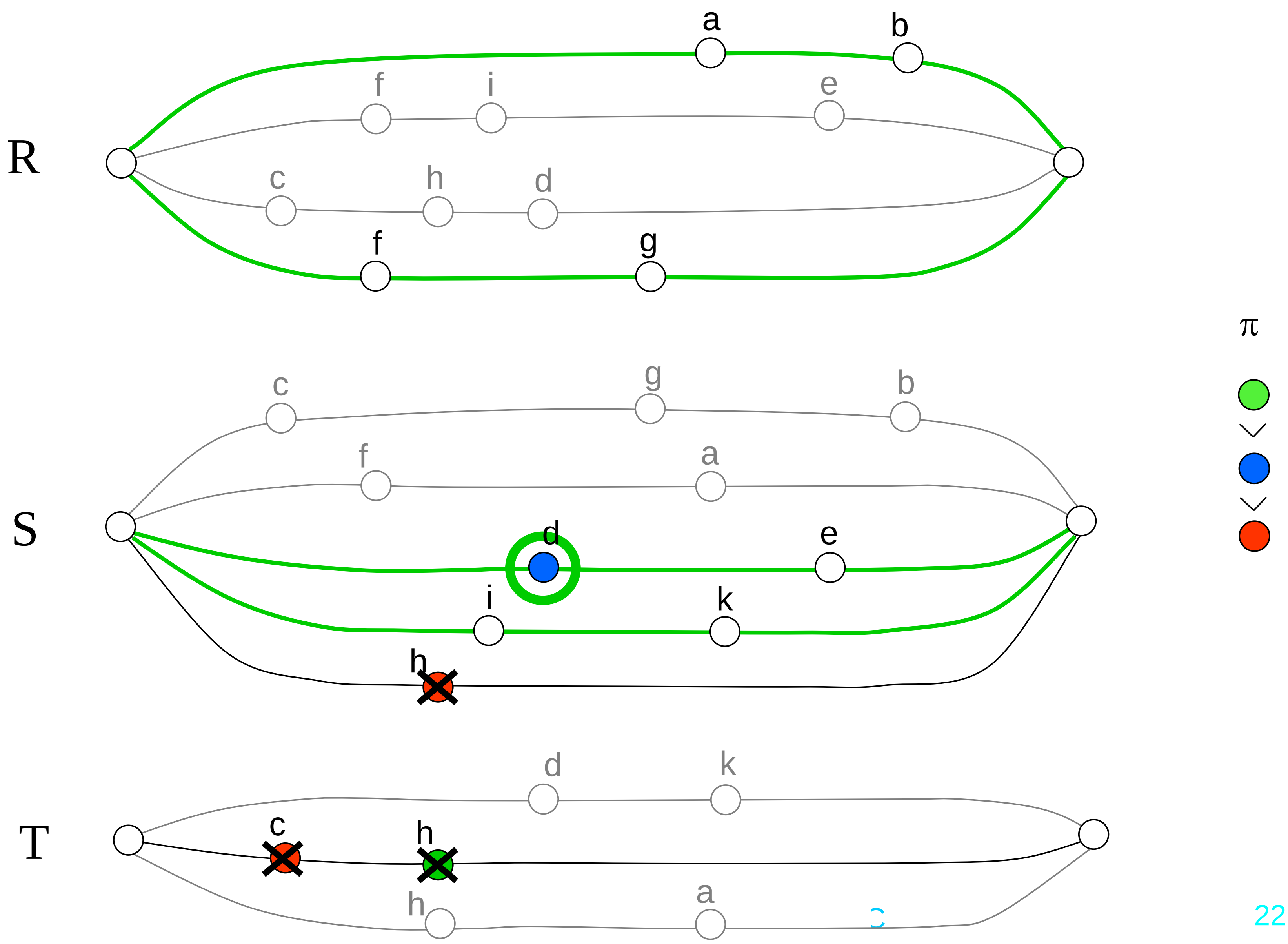
The algorithm



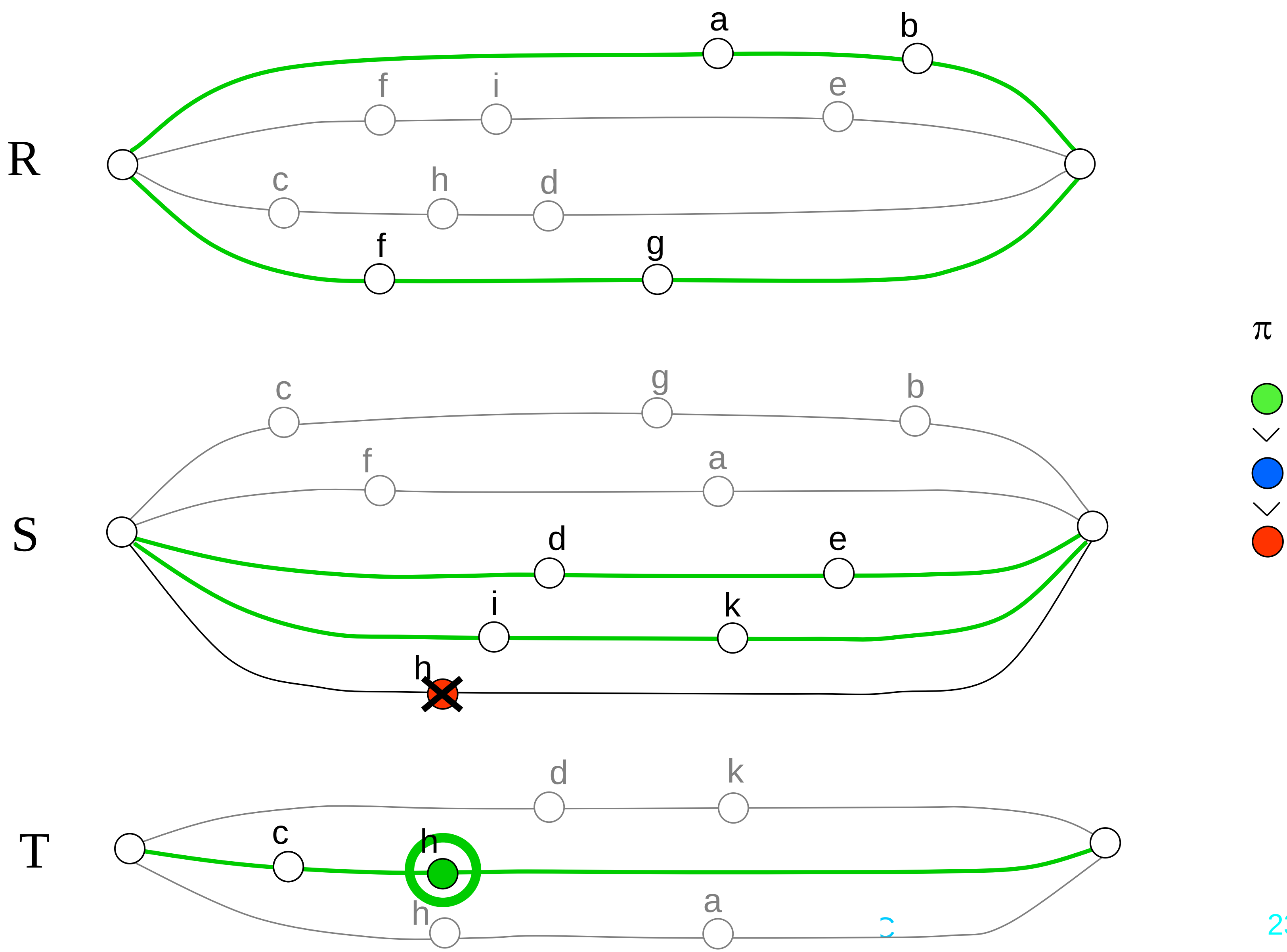
The 2nd iteration



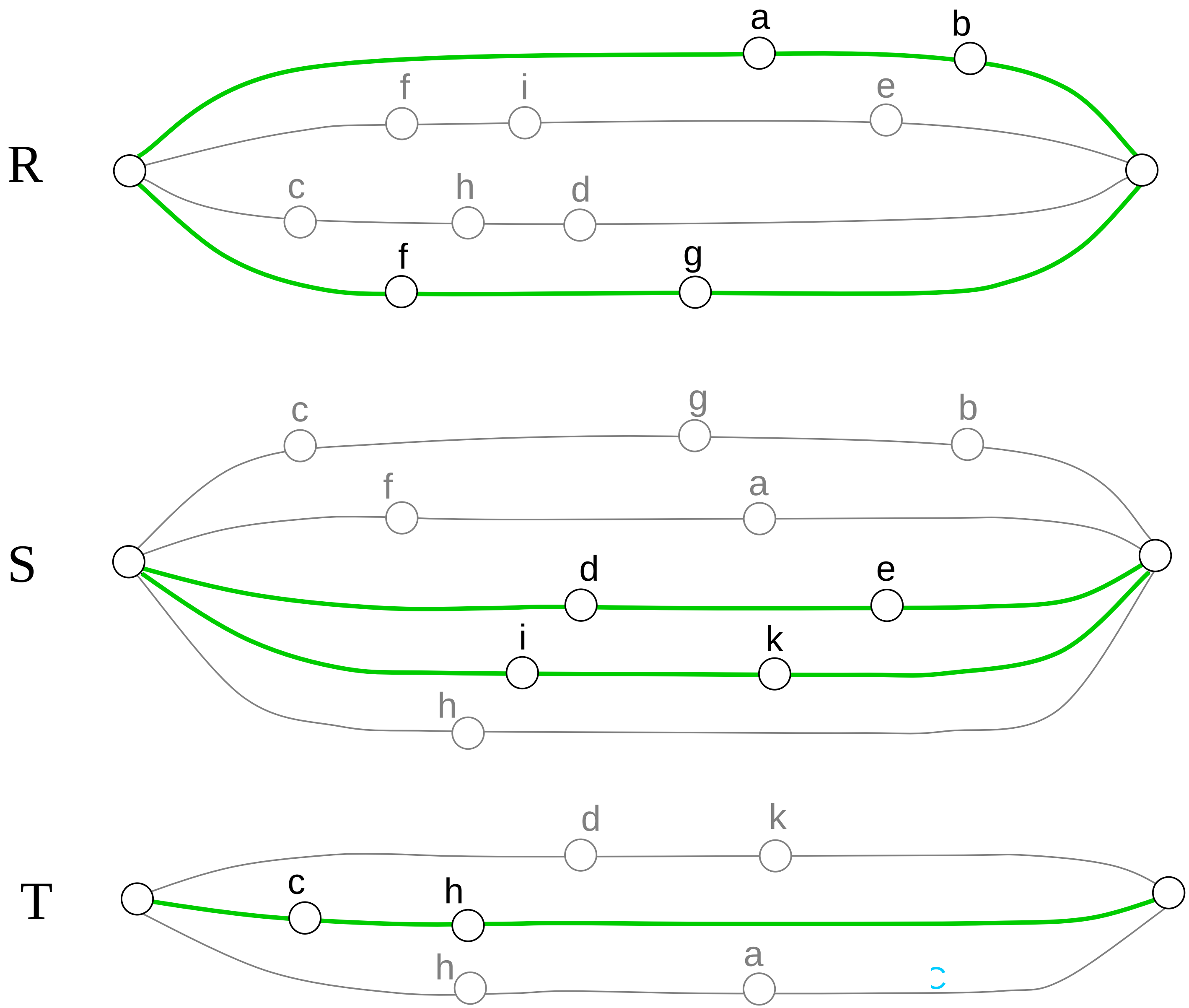
The 2nd iteration



The 3rd iteration



Solution



Theorems

Properties of algorithm:

1. The algorithm terminates with computational complexity of

$$O(n(e) \cdot n(P)^2)$$

2. There is a unique solution that satisfies the resolution principle

3. The solution is safe

4. The solution is maximal (Nash equilibrium)

Other domains

	INTERPRETATION	
model	ATM	remote lab
resource	*dt´ dr*	*dt´* device
trajectory	G	valid experiment
agent	flight	experimenter
conflict	occupancy	occupancy
maximality	utility of Air Space	utility of RL

Future Work

- priority function p as a process control variable
- other rules of behavior
- algebraic structure
- accommodation

Summary

- new formalism for multi-agent systems
- ordered sequences of resources
- safe and effective conflict resolution
- motivation: ATM
- other domains of application
- future work